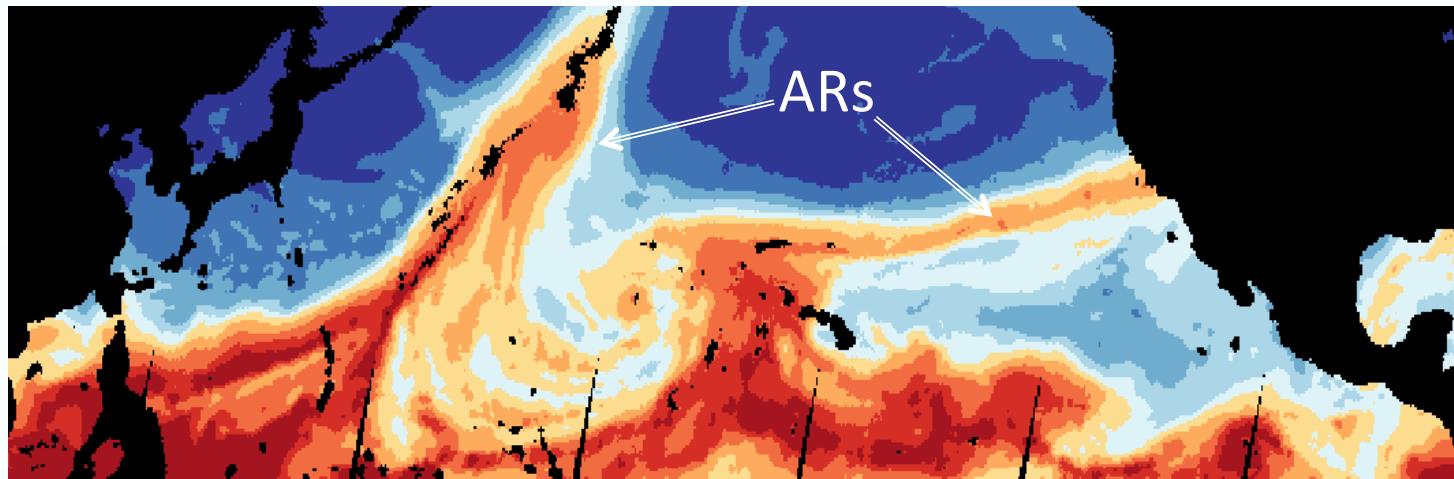


Atmospheric Rivers*: Water Extremes that Impact Global Climate, Regional Weather & Water Resources



Duane Waliser¹, Bin Guan³, Marty Ralph²

¹NASA Jet Propulsion Laboratory, Caltech

²Center for Western Water and Weather Extremes, SIO, UCSD

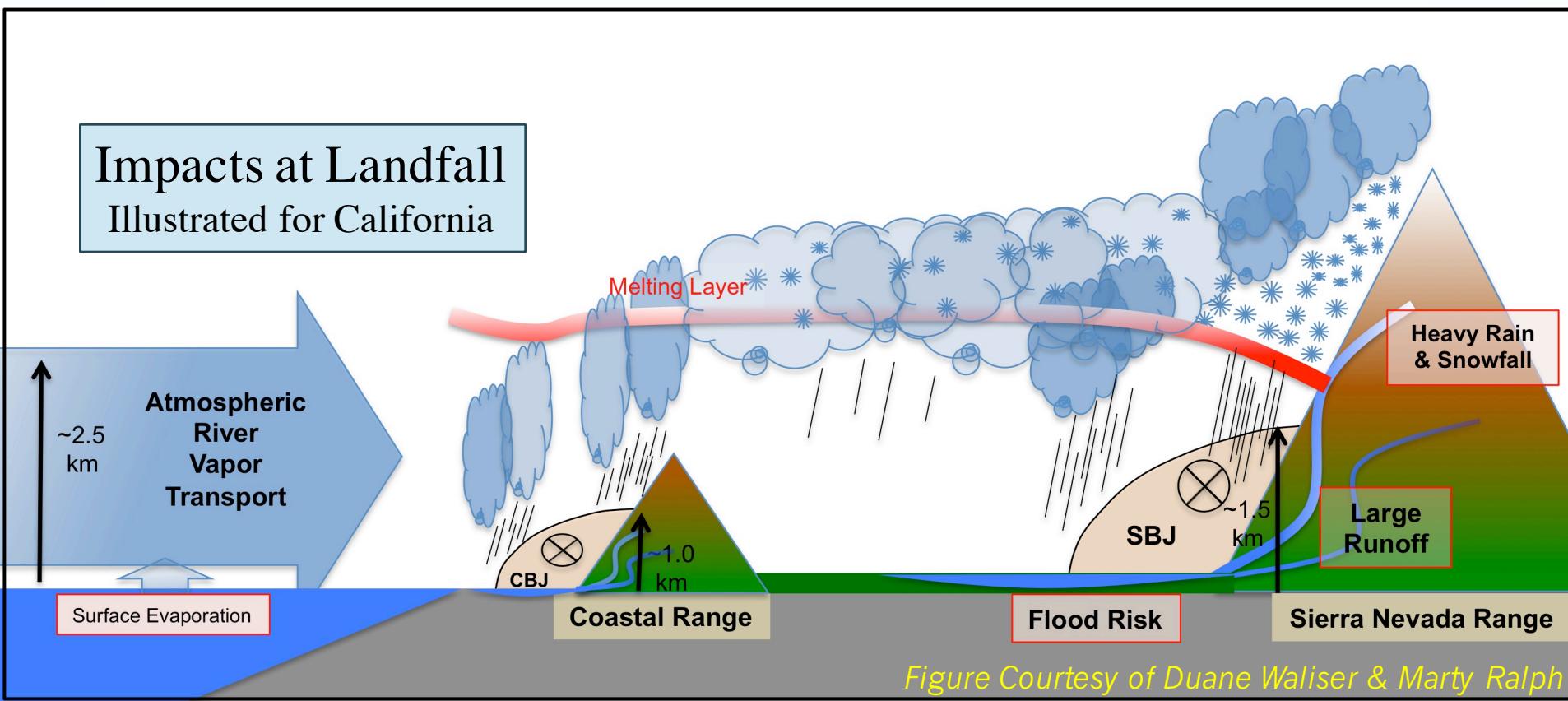
³Joint Institute for Regional Earth System Science and Engineering, UCLA

Support from NASA NEWS, MAP & NCA

*Name from Zhu & Newell, 1994; ARs transport ~10 times the flow of the Mississippi River

When Atmospheric Rivers Make Landfall Extreme Precipitation Occurs Near Mountains

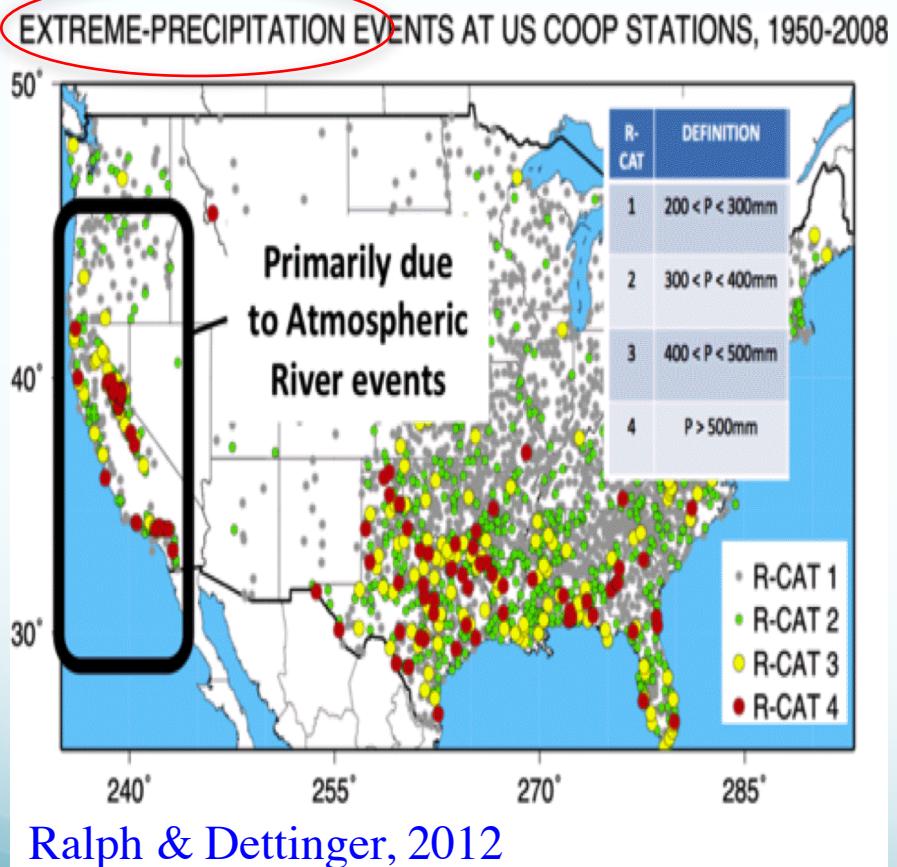
Impacts at Landfall Illustrated for California



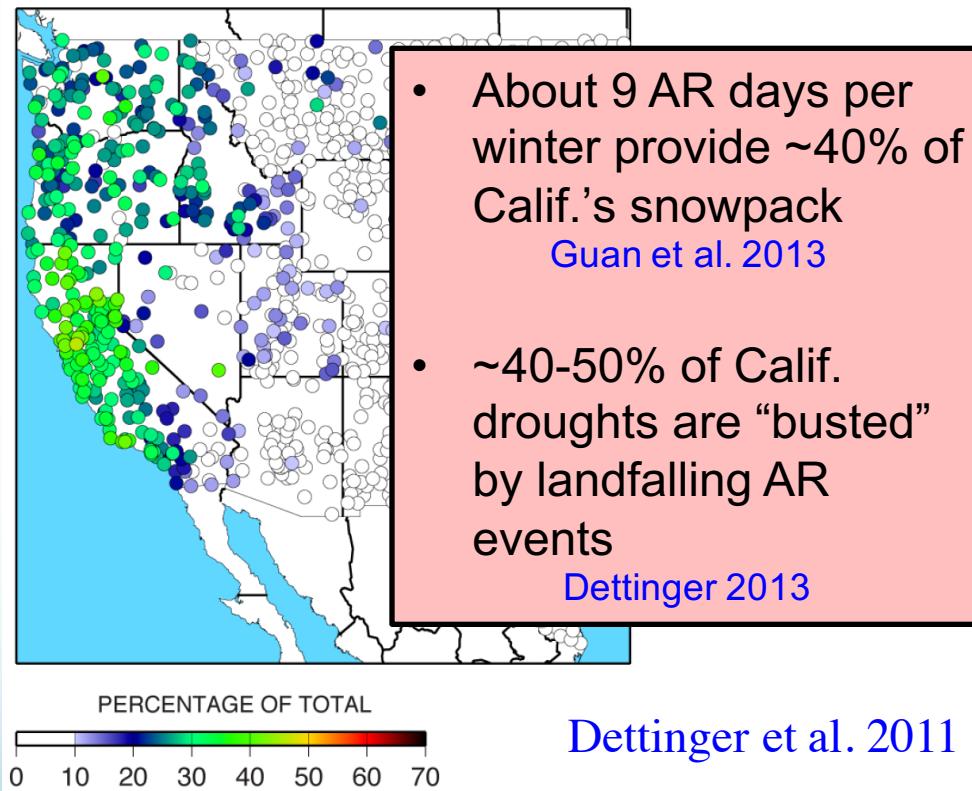
Most flooding / peak streamflow in U.S. coastal states is associated with ARs
(e.g. Ralph et al. 2006; Neimen et al. 2011)

Atmospheric Rivers are to the West What Hurricane Hazards are to the Southeast

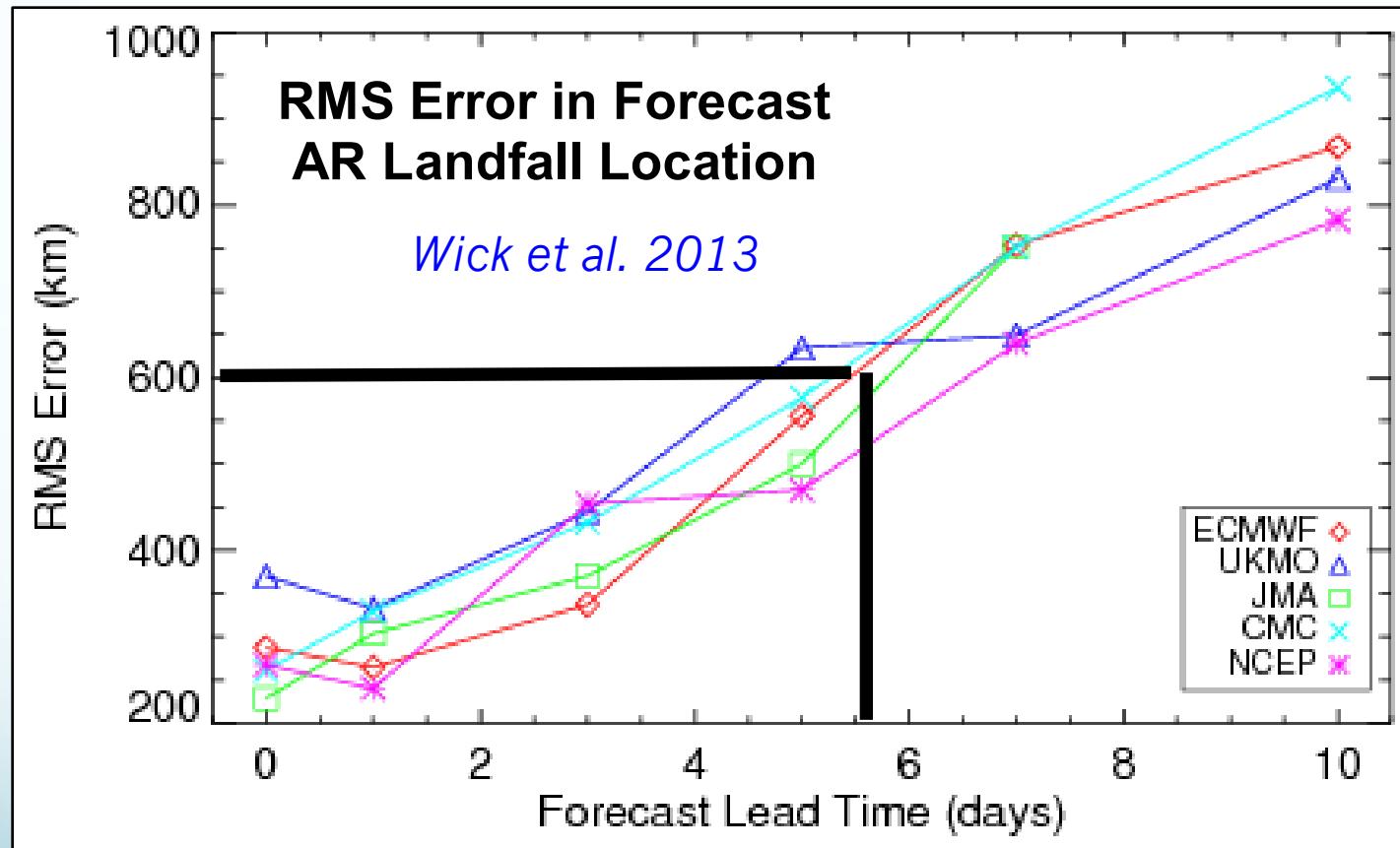
Atmospheric Rivers account for 30-40% of the freshwater supply in the West



CONTRIBUTIONS OF ALL AR EPISODES (days 0 to +1) TO TOTAL PRECIPITATION, WY 1998-2008



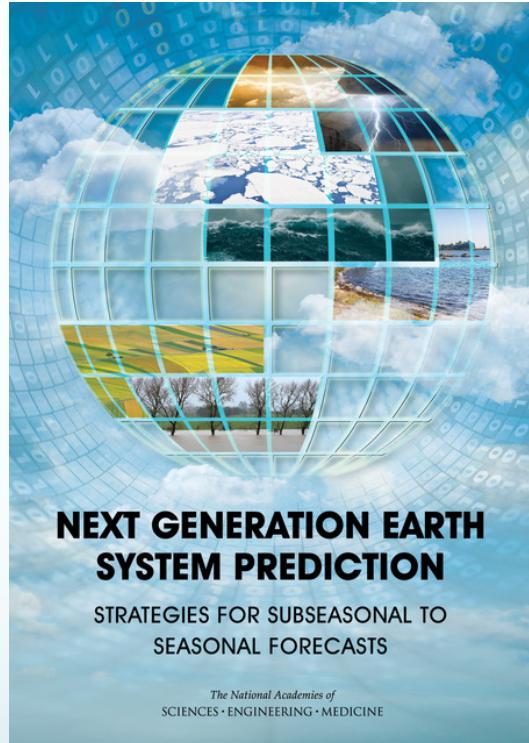
Forecasts of Timing and Location of AR Landfall Needs to Improve



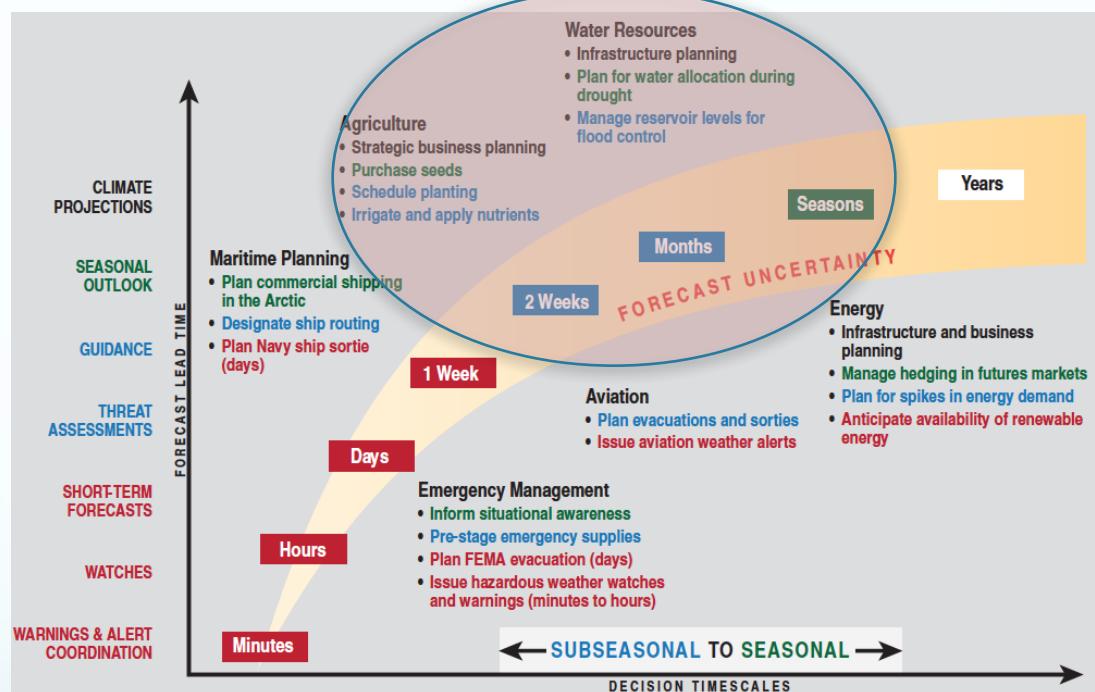
For example: at 5-6 day lead time, global weather forecasts cannot determine if AR will hit L.A. or San Francisco

A key objective of our current research is to more thoroughly quantify AR prediction skill and estimate their predictability under various climate conditions.

2016 National Academy Study: Strategies for Subseasonal to Seasonal Prediction

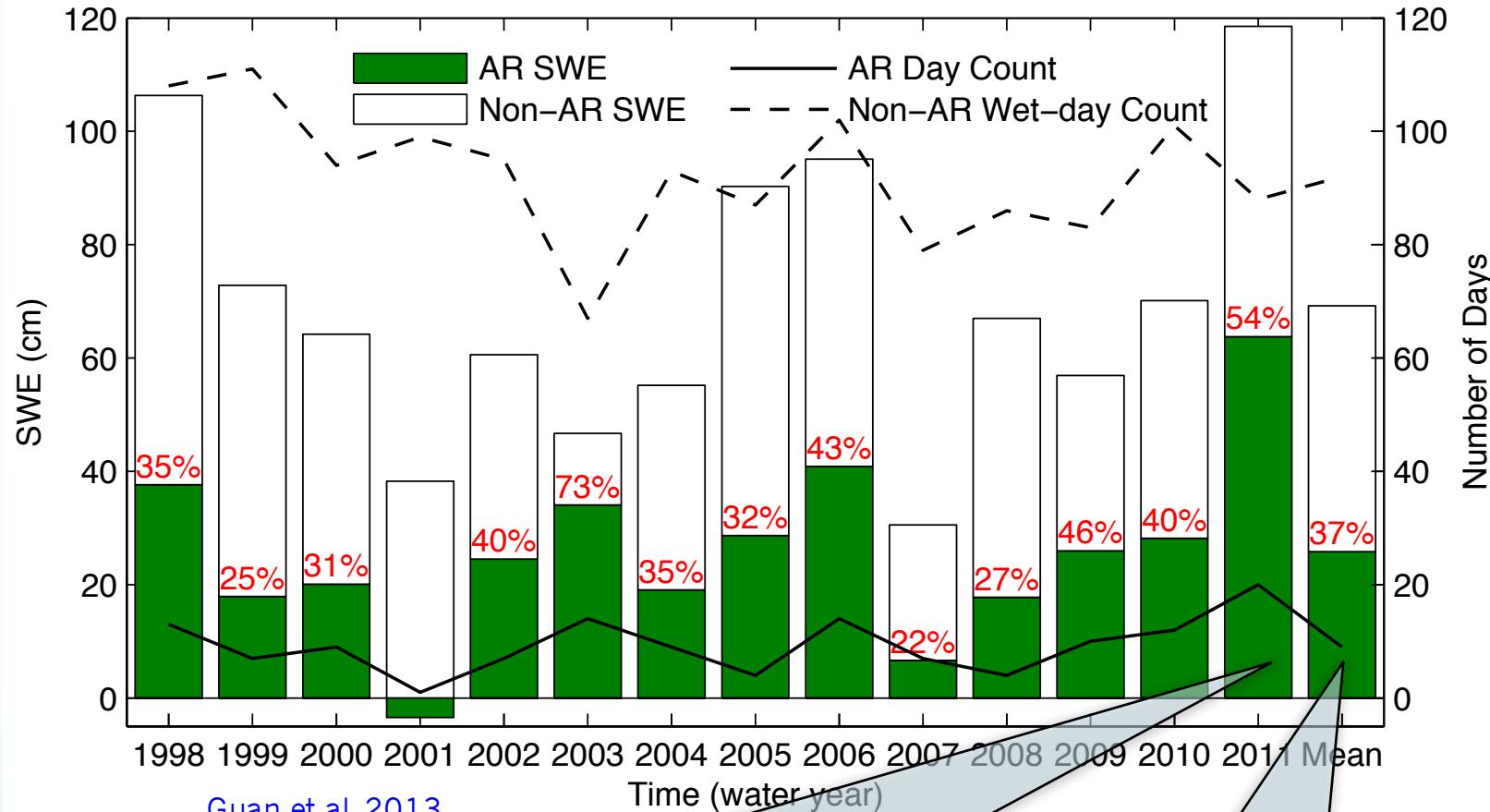


Opportunities for Water Management



Sponsored by NASA, ONR and Heising-Simons Foundation

The Unusually Snowy Winter of 2010/2011

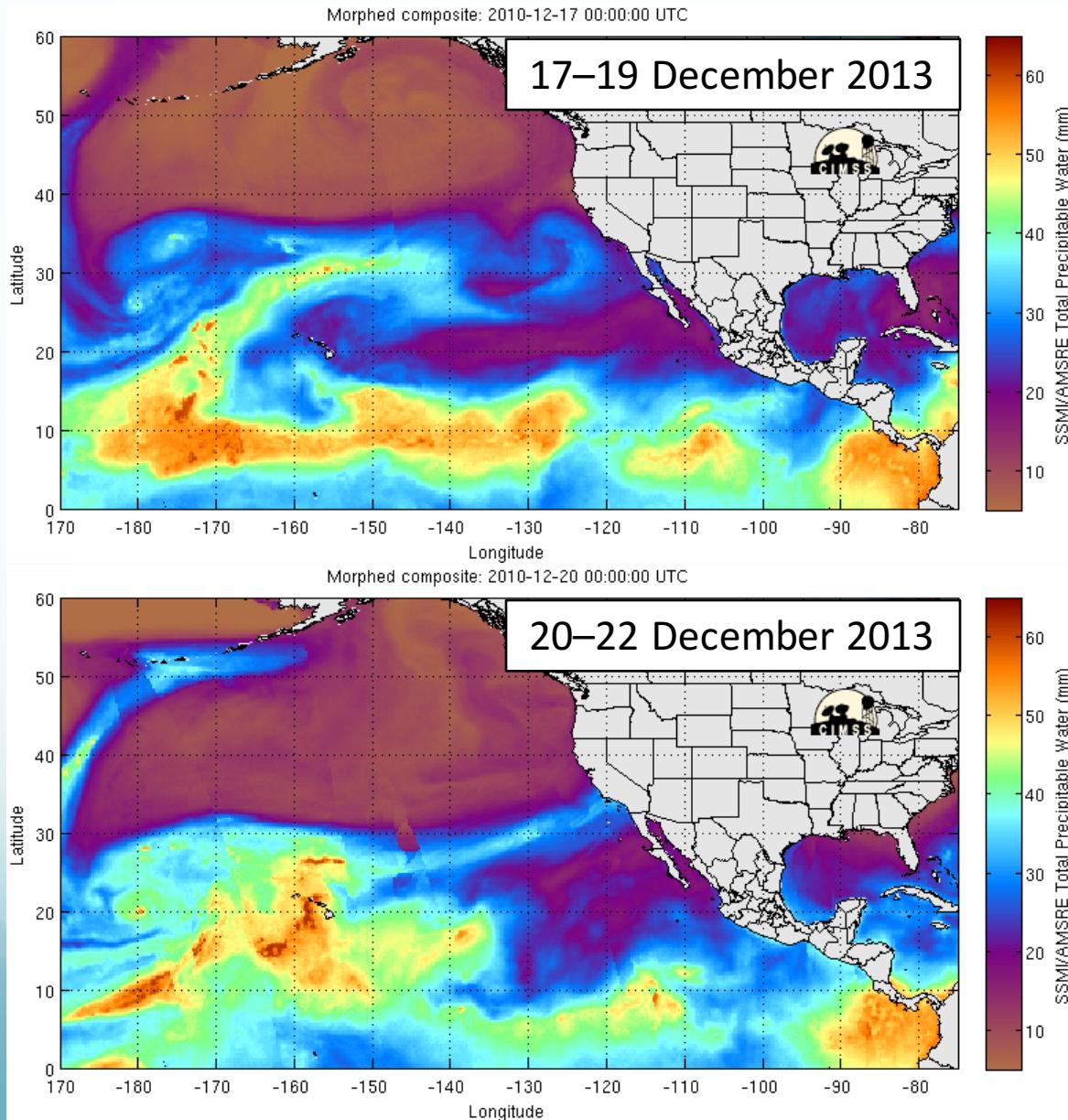


2010/2011 winter

- Largest total seasonal snow (~170% above normal)
- Largest number of AR dates (twice normal)
- Largest AR-related snow accumulation

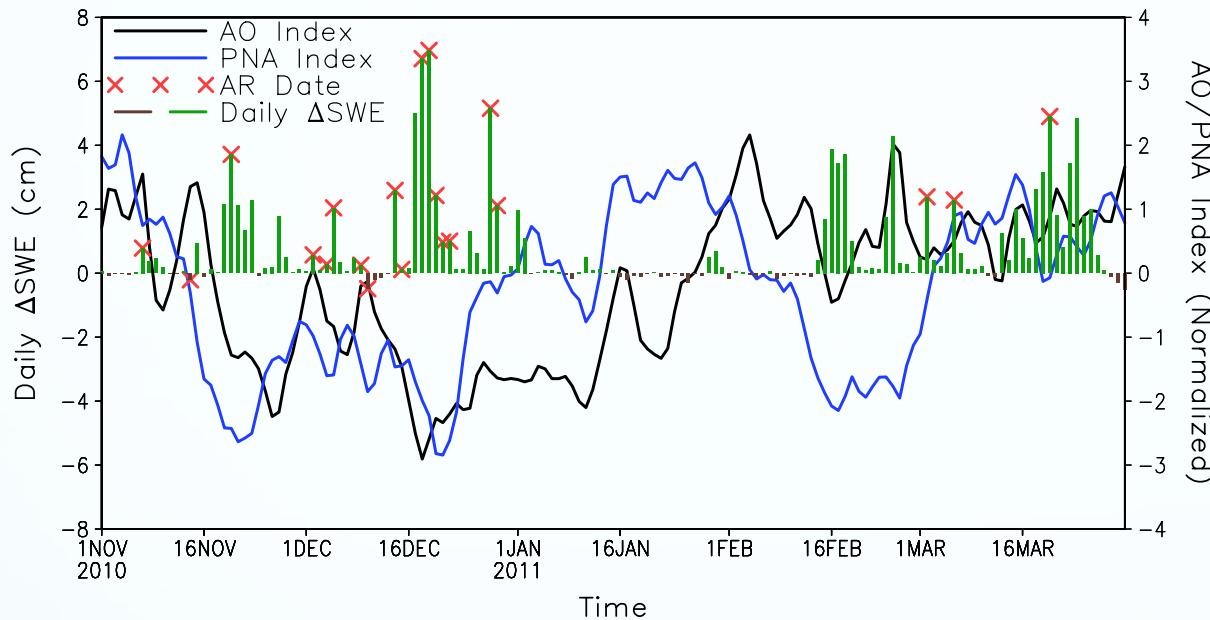
On average 9 AR dates per winter contribute 37% total snow

Dec 18 to 22 – Five Straight Days of ARs

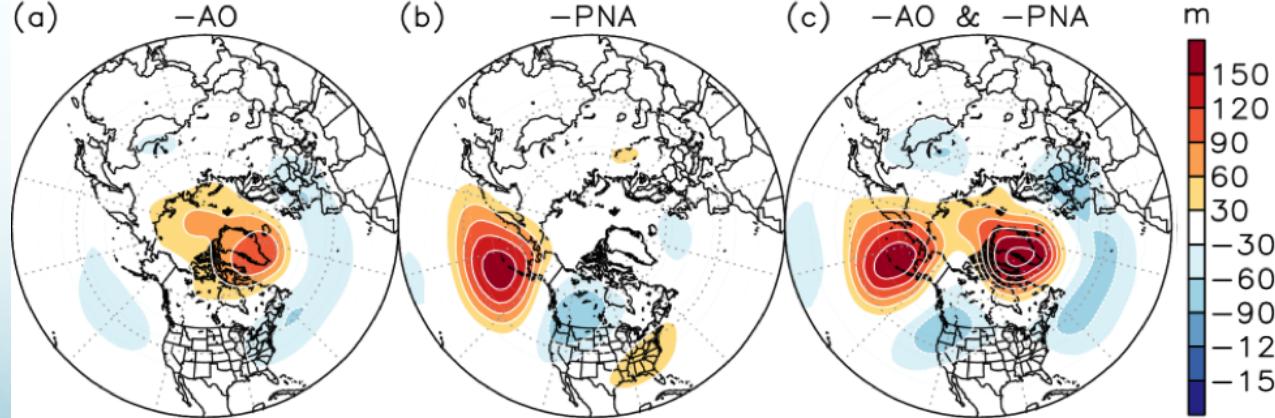


- >13 feet of snow in the Sierras
- >6 inches of rain in LA and >21 inches in parts of the foothills
- Spread into Nevada/Arizona/Utah ; Zion NP evacuated

Climate Conditions of the 2010/2011 Winter



-AO and -PNA tend to be associated with more stormy weather in California



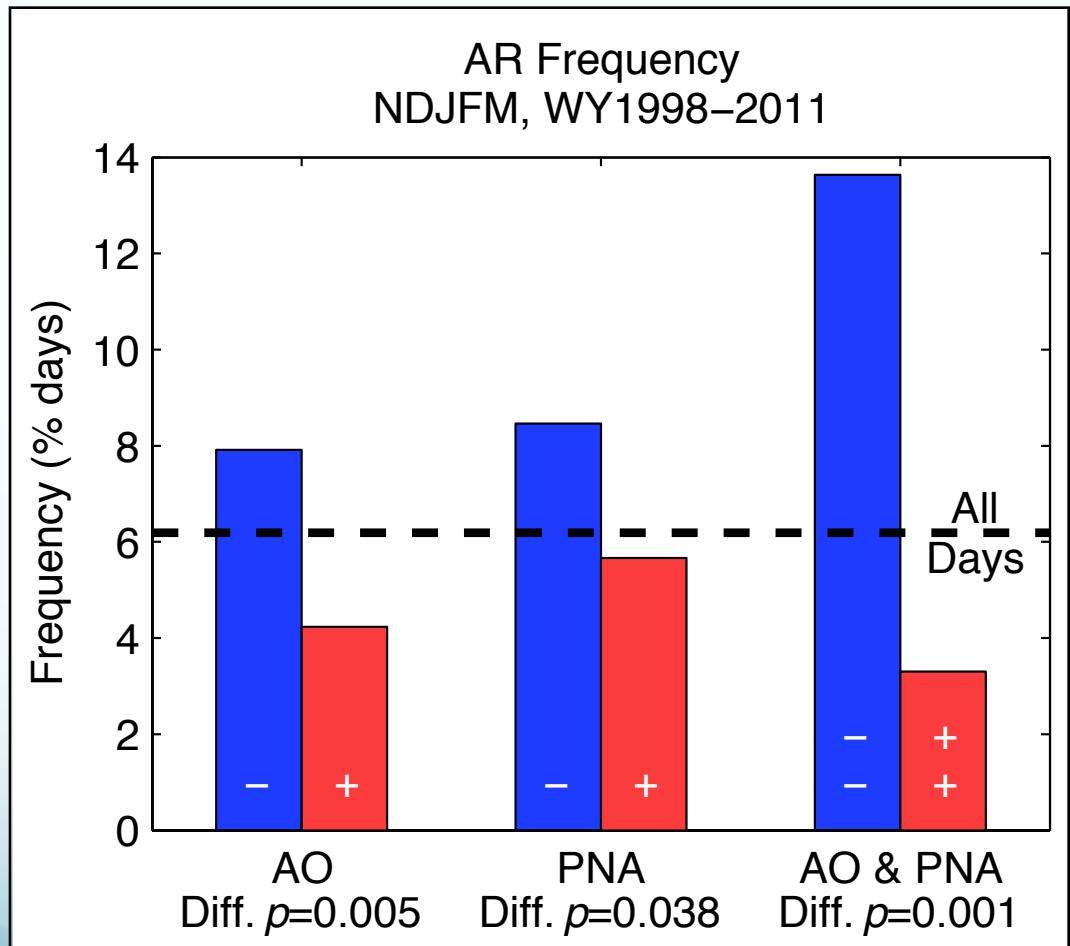
“Arctic Oscillation”
(AO)

“Pacific North American” (PNA)

Both PNA and AO in
“negative” phase

500 mb
Geopotential
Height
Anomalies

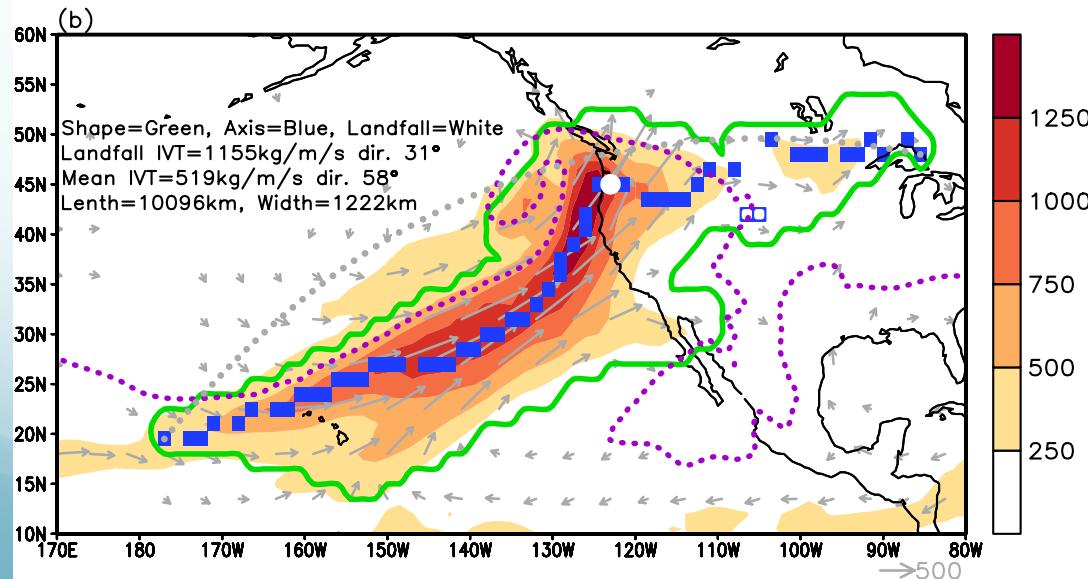
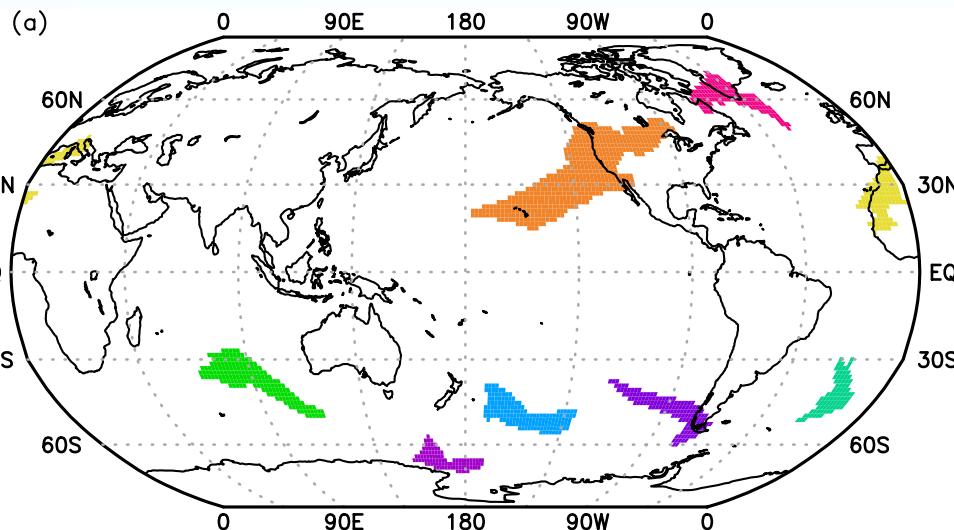
Phasing of AO/PNA vs. AR Frequency in California



When the AO and PNA are both in the negative phase, ARs are significantly more likely to occur.

Global AR Detection

Example Output of AR Shape, Axis, Landfall Location, Etc.

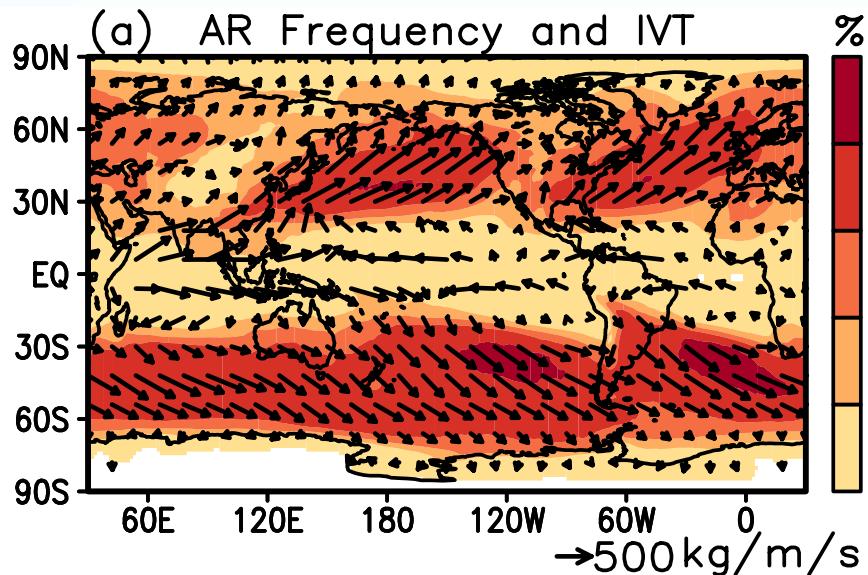


Based on ERA-Interim 6-hourly IVT

ERA-I: 1979-2015
MERRA2: 1980-2015
NCEP/NCAR: 1948-2015
CFSR: TBS

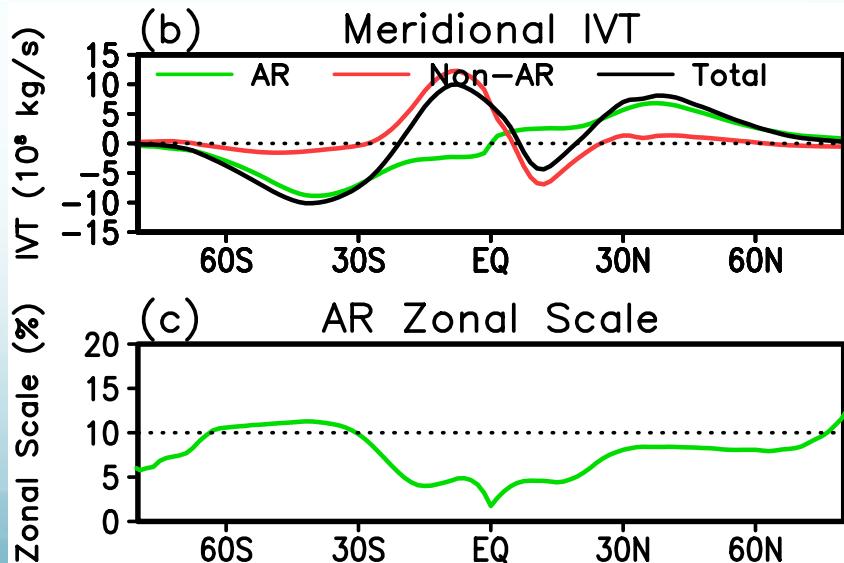
Global View of AR Frequency & Intensity

Relevant to Climate & Water Extremes

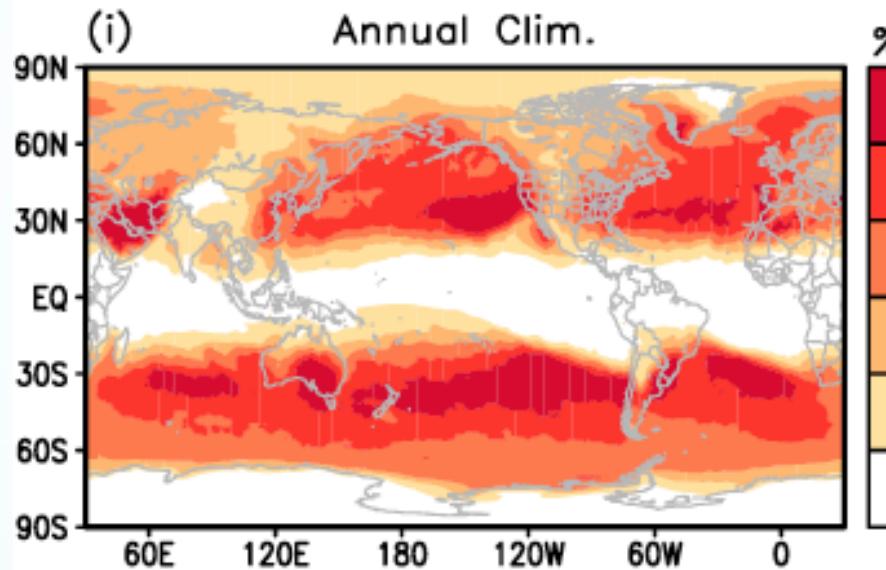


AR fractional poleward IVT and zonal scale consistent with Zhu and Newell (1998)

- **Northward component** key to climate – water vapor distribution and thus energy and water cycles
- **Eastward component** key to landfalls, inland penetration, and weather/water extremes

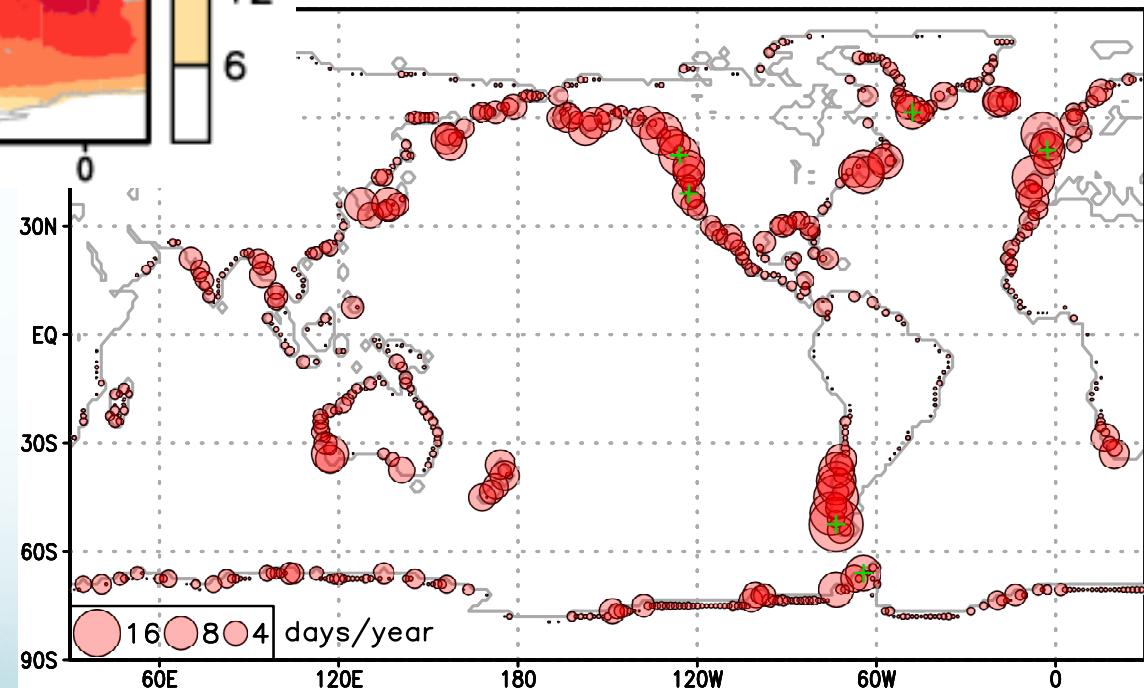


Global View of AR Precipitation & Landfalls

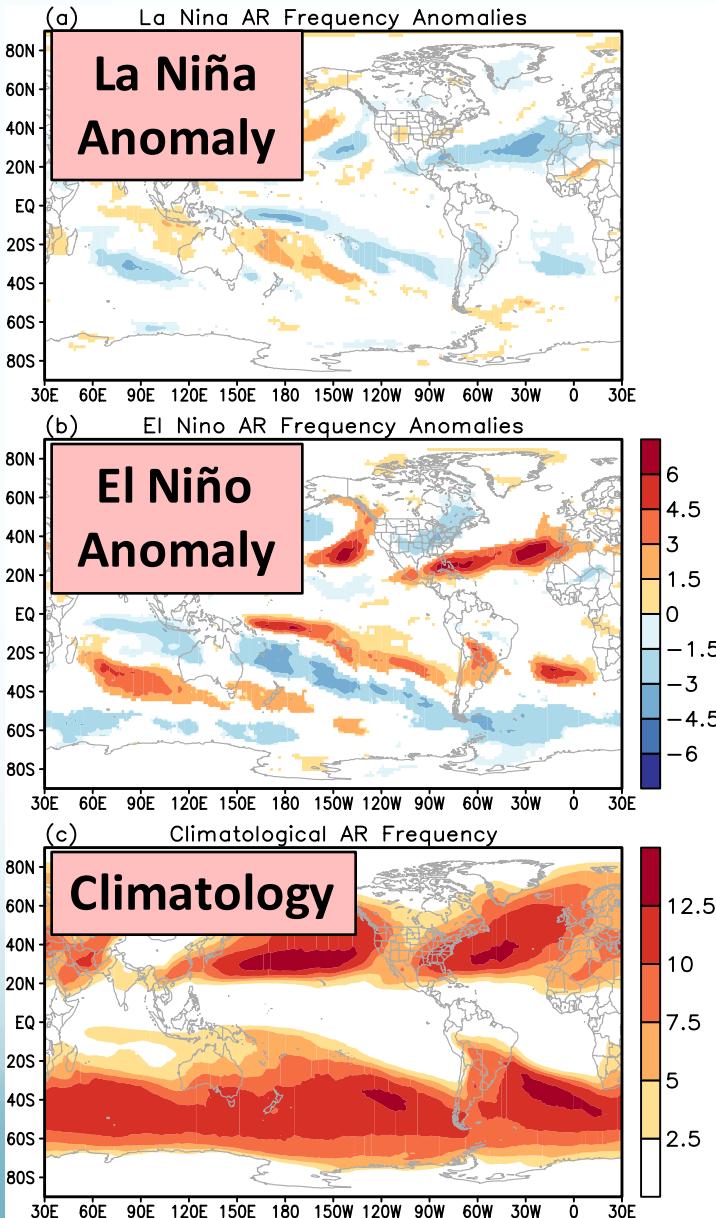


Fraction of Total
Precipitation Due to ARs

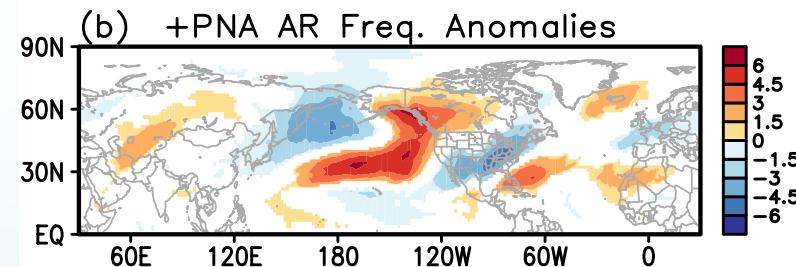
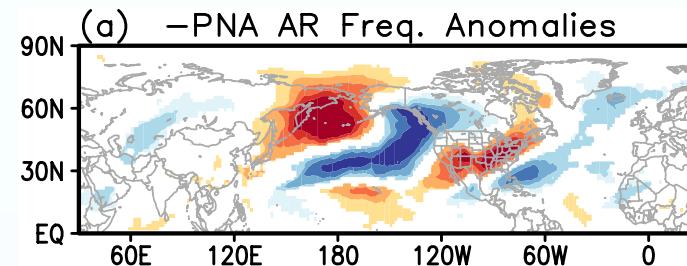
Number of AR
Landfalls per year



Quantifying Climate Modulation of Global ARs

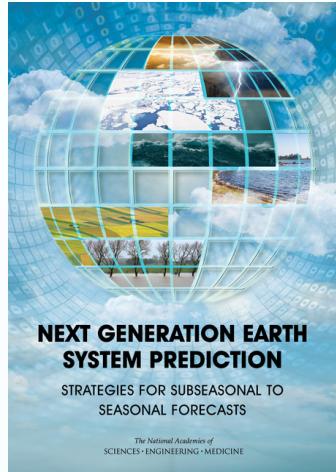


Pacific-North American



Similar results also for
Arctic Oscillation
Madden-Julian Oscillation

Water/Flood Management at 2 Week to 2 Month Leads

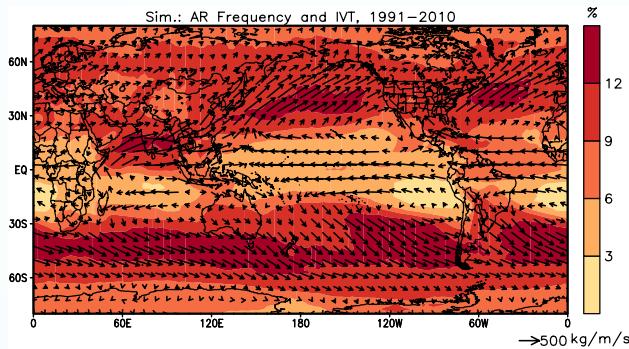


Relies on weather/climate forecast model fidelity for

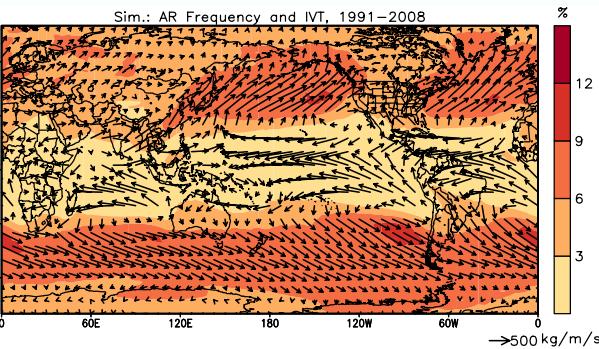
- Atmospheric Rivers
- Low-frequency variations (e.g., ENSO, MJO, AO, PNA)
- Their Interaction

Model Evaluation : Bias of AR Frequency & IVT

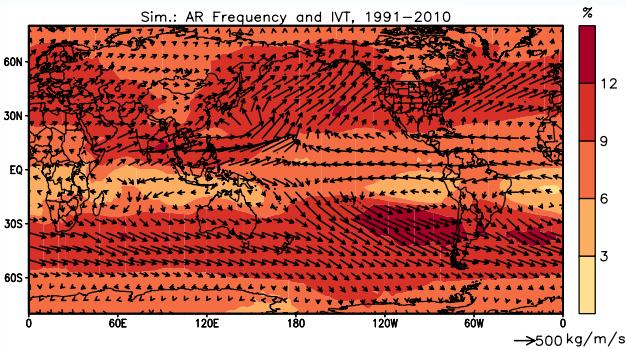
01_NASAGMAO_GEOS5



17_MetUM_GA3



35_BCCAGCM2.1

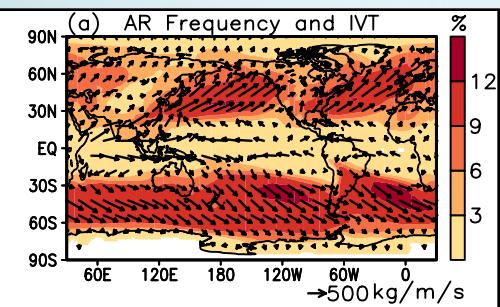


Reasonable representation

Global negative bias in AR frequency

Tropical positive bias in AR frequency

Observations



YOTC/MJOTF+GEWEX GASS Multi-Model Experiment
(3 out of 28 models; work in progress)

Current and Future Work

- ARL 1 - Continue GCM and physical process evaluation, including using CalWater airborne experiment data – working toward atmospheric and terrestrial water budgets
- ARL 2-3 Continue global and regional AR impact studies (e.g. extreme precipitation, rain on snow, impact on ice sheet mass balance, wind hazards)
- AR 3-8 Synoptic, subseasonal and seasonal prediction skill and predictability studies with WCRP-WWRP S2S Project Database – with some emphasis on operations and decision support (e.g. CA DWR).

Guan and Waliser (2015, JGR), Detection of atmospheric rivers: Evaluation and application of an algorithm for global studies.
Guan, Waliser, Ralph, Fetzer and Neiman (2016, GRL), Hydrometeorological characteristics of rain-on-snow events associated with atmospheric rivers.
Guan, Molotch, Waliser, Fetzer and Neiman (2013, WRR), The 2010/2011 snow season in California's Sierra Nevada: Role of atmospheric rivers and modes of large-scale variability
Guan, B., D. E. Waliser, N. Molotch, E. Fetzer, and P. Neiman (2012), Does the Madden-Julian Oscillation Influence Wintertime Atmospheric Rivers and 1 Snowpack in the Sierra Nevada?, *Monthly Weather Review*, 140, 325-342.

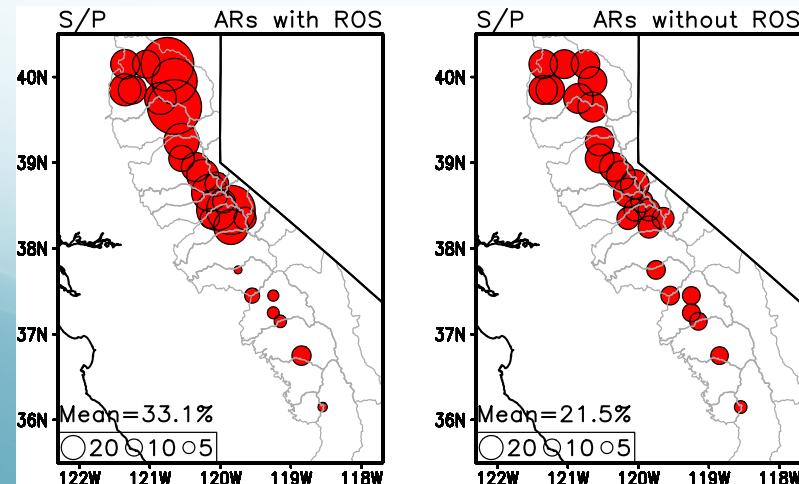
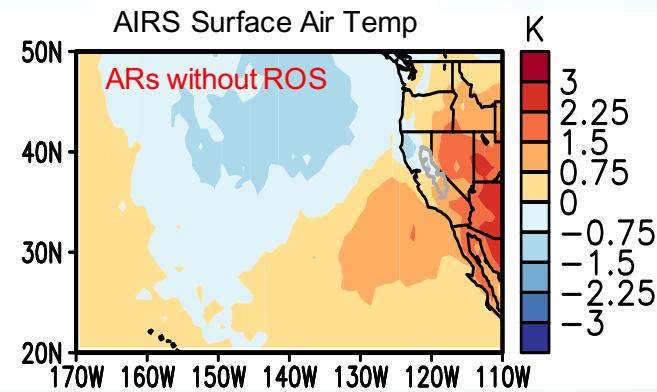
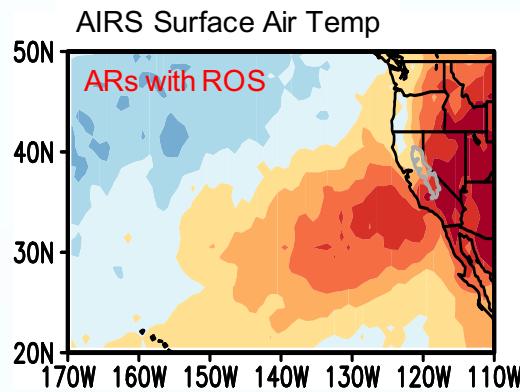
backup

Atmospheric Rivers and Rain on Snow Events



AR conditions are associated with 50% of ROS events during 1998-2014.

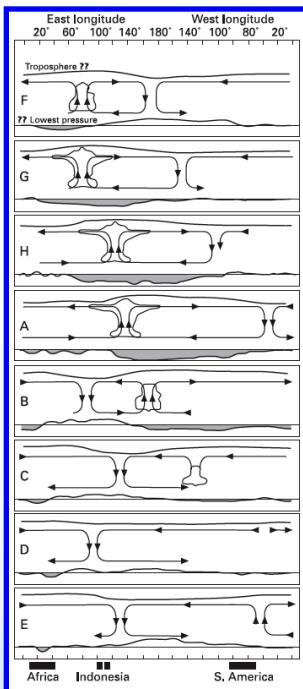
AIRS data, and other sources, show that ARs with ROS are on warmer by ~2° C.



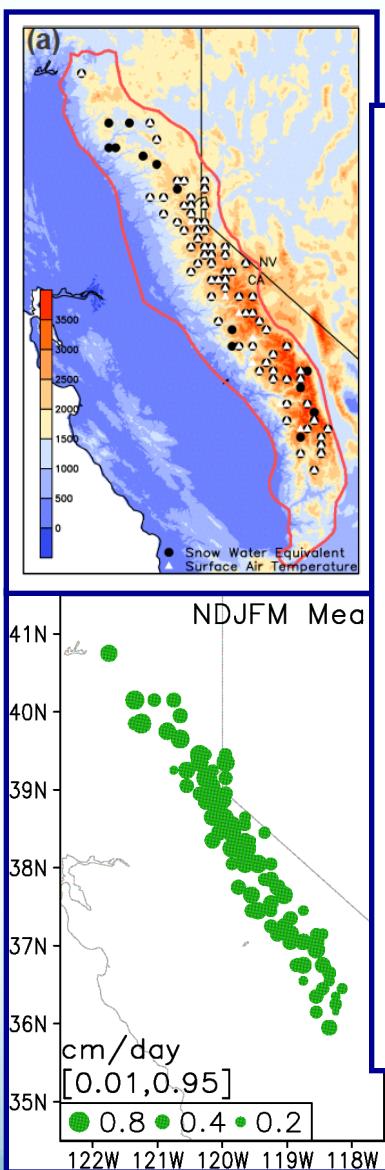
ARs with ROS have 50% higher streamflow/precipitation fraction (in %), i.e. enhanced flood risk.

MJO Influence on Sierra Snowpack

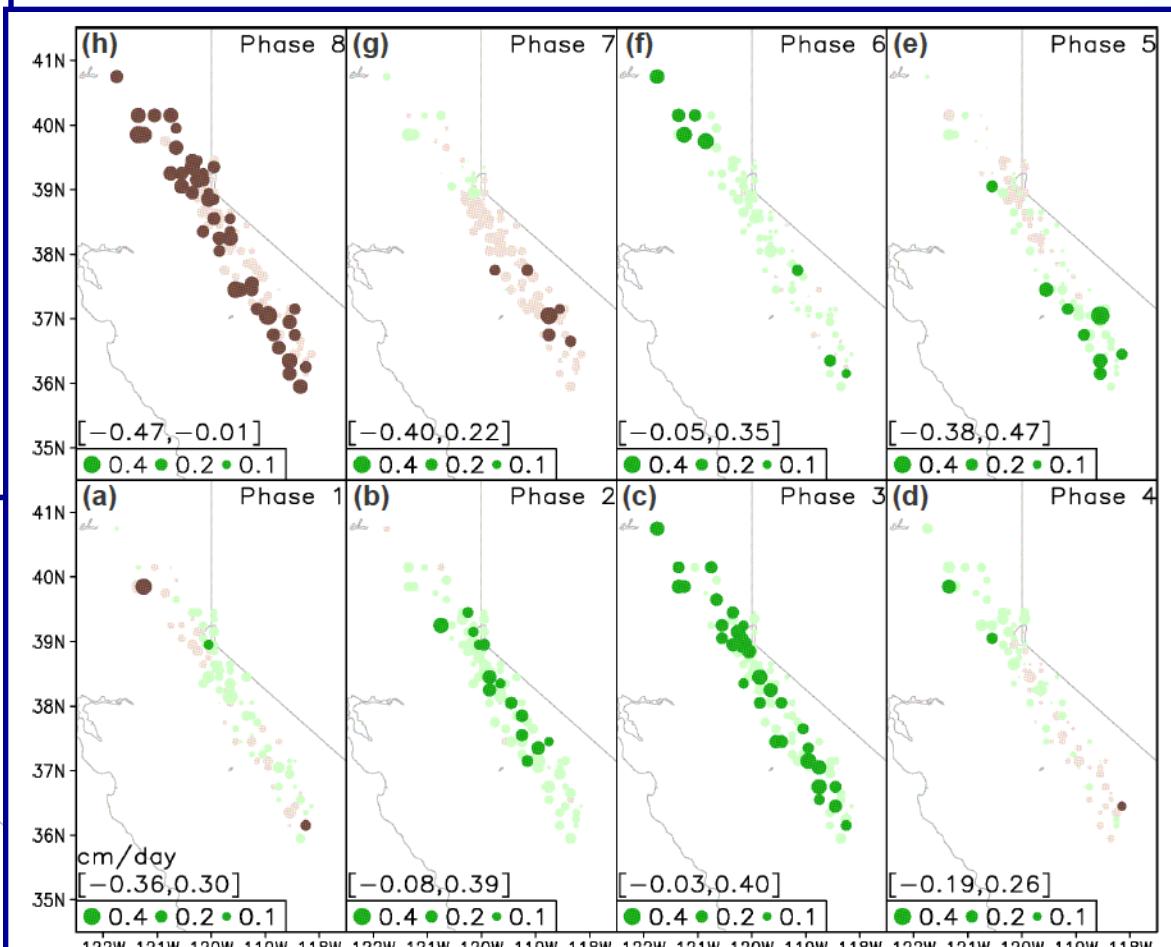
Madden
Julian
Oscillation



40-50 Day
Eastward
Propagating
Tropical
Variation

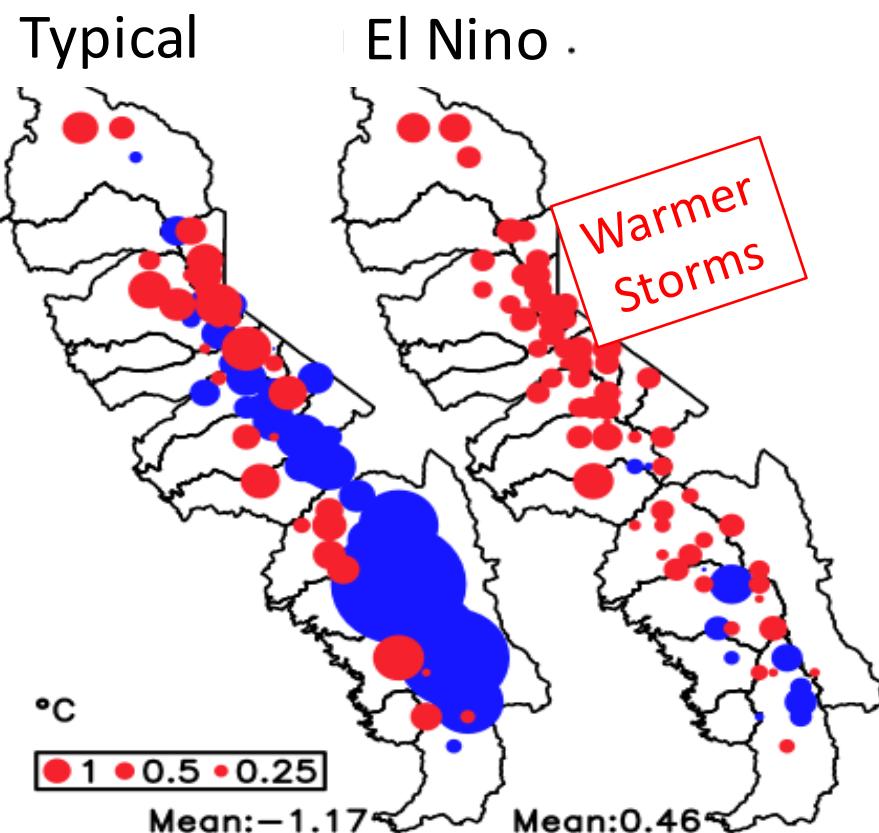


Results Suggests Subseasonal Predictability

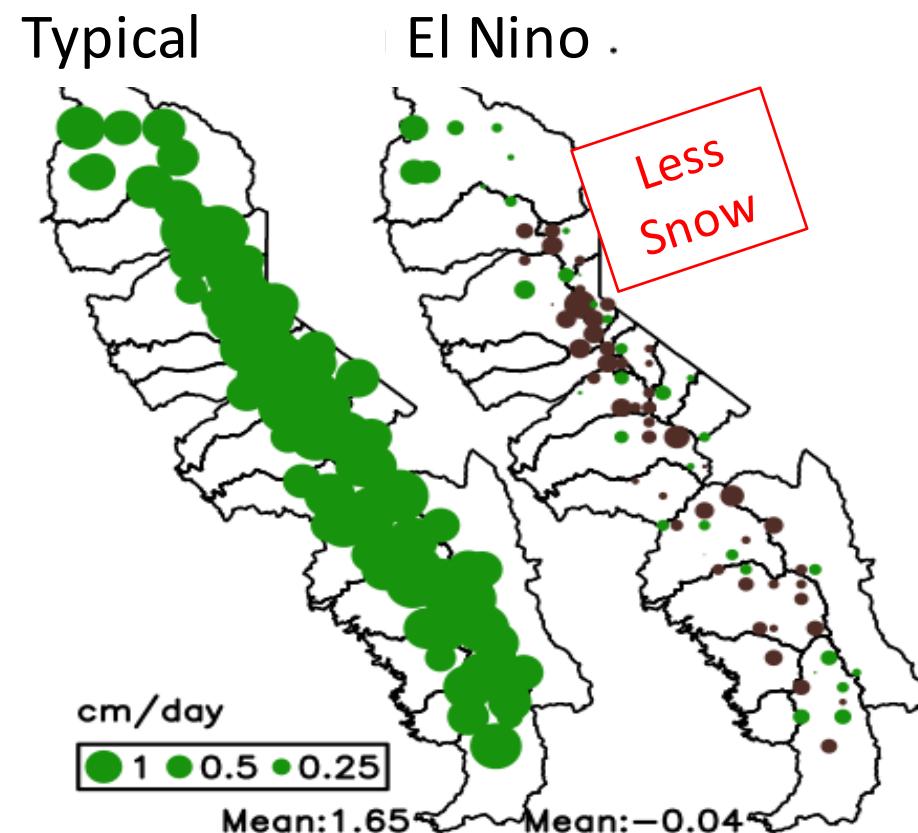


Changes in AR Impacts Due to El Niño

Surface Air Temperatures



Snowpack Accumulation



Result here based on Guan et al. (2013; WRR) using Neimen et al. (2008) IWV AR detection and SNOTEL sites 1997-2011.